Economic Analysis of Management Alternatives Proposed for the Recreational Vermilion Snapper Fishery in the Gulf of Mexico

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Abstract: *This report documents the economic model and analysis of management alternatives proposed in 2004 for the recreational sector of the vermilion snapper fishery in the Gulf of Mexico. The model simulates the annual number of recreational fishing trips that catch and keep vermilion snapper with each alternative over the planning horizon for private boat, charter boat, and head boat anglers. These trip paths and related harvest are used to calculate the total annual consumer surplus to anglers in each mode. Annual net revenue is also calculated for the charter and head boat operators. The difference in consumer surplus and net revenue from the status quo measures the net effect of each alternative in each year over the planning horizon. The net present value of the annual net effects is calculated to summarize the economic outcome of each alternative.*

1. Introduction

The National Marine Fisheries Service has declared that vermilion snapper (*Rhomboplites aurorubens*) in the Gulf of Mexico is overfished and that policies are required to rebuild the population to biologically acceptable levels (NFMS, 2003). Amendment 23 to the Reef Fish Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico considers a wide range of management alternatives for the commercial and recreational fisheries (GMFMC, 2004). Table 1 summarizes the fourteen management alternatives proposed for the recreational sector. This report describes the economic analysis of these management alternatives. A companion report by Waters (2004) describes the analysis of the management alternatives proposed for the commercial fishery.

2. Model

The model used in the analysis of Amendment 23 considers the welfare effects of the proposed management alternatives on individual anglers and owners of the for-hire operations. Both effects depend on the interactions between vermilion snapper biomass and the effort of individual anglers, for-hire operators, and commercial fishing operators. Thus, an integrated bioeconomic model is required to thoroughly analyze the effects of vermilion snapper policies (Anderson, 1993). The present analysis, however, focuses on the recreational sector and takes as given the annual biomass and commercial harvest associated with each rebuilding strategy over the planning horizon. Only the response of aggregate recreational effort is formally modeled.

Table 1. Proposed Management Alternatives for the Recreational Vermilion Snapper Fishery

Alt.	Rec. Sector Allocation (%)	Rebuilding Strategy	Proposed Bag Limit (fish)	Proposed Minimum Size (TL)	Proposed Closed Season	Initial Harvest Reduction (%)
1	21	Status quo	20	10	None	0
2	21	Steps	2	10	None	30
3A	21	Steps	10	11	None	21.5
3B	21	Steps	7	11	None	25.6
4	33	Steps	20	10	None	25.5
5	21	Steps	20	10	5/1-6/21	25.5
7A	33	Status quo	20	10	None	0
7B	33	Const h	20	10	None	17.9
7D	33	Steps (2010)	20	10	None	50.5
7E	33	Const f	20	10	None	38.7
8B	21	Const h	20	10	None	17.9
8C	21	Steps	20	10	None	25.5
8D	21	Steps (2010)	20	10	None	50.5
8E	21	Const f	20	10	None	38.7

The annual level of harvest, H_t, available from a rebuilding plan is converted to the number of fish allocated to recreational mode m as follows:

(1) $$h_t^m = \bar{v}^m \frac{H_t}{\bar{w}^m}$$

where $\bar{v}^m$ and $\bar{w}^m$ are, respectively, the (historic) average share of vermilion snapper catch and average weight per fish for mode *m*.[1] It is assumed that, without any policies (bag limit, minimum size, etc.), all of the h^m fish are caught and kept by anglers in mode *m*. Therefore, the average annual catch and keep per trip, or *catch rate*, is

$$c_t^m = \frac{h_t^m}{E_t^m} \tag{2}$$

where E_t^m is the total number of trips where vermilion snapper were caught and kept by mode *m* in year *t*.

The change in annual trips for mode *m* is governed by the (arc) elasticity of trips with respect to the catch rate

$$\begin{aligned} e &= \frac{\%\Delta E}{\%\Delta c} \\ &= \frac{\dfrac{E_t^m - E_{t-1}^m}{0.5\left(E_t^m + E_{t-1}^m\right)}}{\dfrac{c_t^m - c_{t-1}^m}{0.5\left(c_t^m + c_{t-1}^m\right)}} \end{aligned} \tag{3}$$

With a starting value for trips, E_0^m, a vector of total annual harvest, $\mathbf{H} = \{H_0, H_1, \ldots H_T\}$, and estimates of e, $\bar{v}^m$, and $\bar{w}^m$, numerical methods can be used to solve for the values of E_t that maintain the equality in (3) over the planning horizon.[2] For example, consider the following parameters for mode *m*: $\bar{v}^m$ = 0.20, $\bar{w}^m$ = 0.89, and e = 1.46. Assuming the first period effort is E_0^m = 0.049 million trips and the recreational harvest in the first two periods are H_0^m = 2.63 and

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[1] *Mode* refers to how the angler gets to the fish or fishing spot. The present analysis considers private boat, charter boat, and head boat modes. Vermilion snapper are not generally caught from the shore.

[2] The analytical solution to this problem is discussed in the Appendix.

H_1^m = 1.98 million pounds, the second period trips is the solution of the following equation for E_1^m:

$$1.46 = \frac{E_1^m - 0.049}{0.5\left(E_1^m + 0.049\right)} \Bigg/ \frac{0.09/E_1^m - 0.12/0.049}{0.5\left(0.09/E_1^m + 0.12/0.049\right)}$$

Repeating this process over the planning horizon for each harvest value in **H** will generate corresponding vectors for aggregate effort and the catch rate in mode *m*. These vectors can be used to calculate the aggregate welfare associated with each rebuilding strategy. First, however, two adjustments are made to account for minimum size and bag limit policies.

2.1. Minimum Size Adjustment

The average weight per fish in each mode, $\bar{w}^m$, is adjusted to reflect existing or proposed minimum size limits, s*. Specifically, the annual distribution of weight per fish is used to estimate the expected weights with different minimum size constraints. In effect, a minimum size limit censors the range of potential fish weights from below so that the adjusted expected weight is $\bar{w}^m(s^*) = E\left[w^m \middle| s \geq s^*\right]$ where *s* is the size of the fish measured as total length. This effect is demonstrated in Figure 1.[3] The top panel shows the unconditional expected weight and the lower panel depicts the larger expected weight associated with a minimum size limit.

For a discrete distribution of weights (and lengths) the expression for conditional expected weight can be approximated as

$$\text{(4)} \qquad \bar{w}^m(s^*) = E\left[w^m \middle| s \geq s^*\right] \approx \frac{\sum_s n_s \cdot w_s}{\sum_s n_s} \qquad \forall s \geq s^*$$

[3] The normal distribution is used for illustration purposes only and is not meant to imply that weights are normally distributed.

where n_s is the number of fish at size *s*. This expression is evaluated beginning with an empirical distribution of sizes. The weights that are roughly equivalent to each minimum size are found using estimated relationships between weight and size. For example, Table 2 shows a hypothetical distribution of total lengths and the related distribution of weights, assuming[4]

$w = 10^{2.87*Log10(s) - 3.225}$.

The unconditional expected weight (i.e., $s^* = 0$) with this distribution is

*(0.321*4,977 + 0.450*14,611 + 0.611*47,455 + 0.805*54,716) / 121,760 = 0.667 lbs*.

Taking this sum over the distribution above 9 inches gives the expected weight conditional on a 10 inch minimum size is

*(0.450*14,611 + 0.611*47,455 + 0.805*54,716) / 116,783 =0 .682 lbs*.

Thus, an increase in the minimum size increases the average weight of a harvested fish.

Table 2. Hypothetical Distribution of Fish Sizes

Total Length (inches), *s*	Weight (lbs), w_s	Number of Fish, n_s
8	0.217	0
9	0.320	4,977
10	0.450	14,611
11	0.611	47,455
12	0.805	54,716

[4] This weight-length relationship is based on the work of Hood and Johnson (1999).

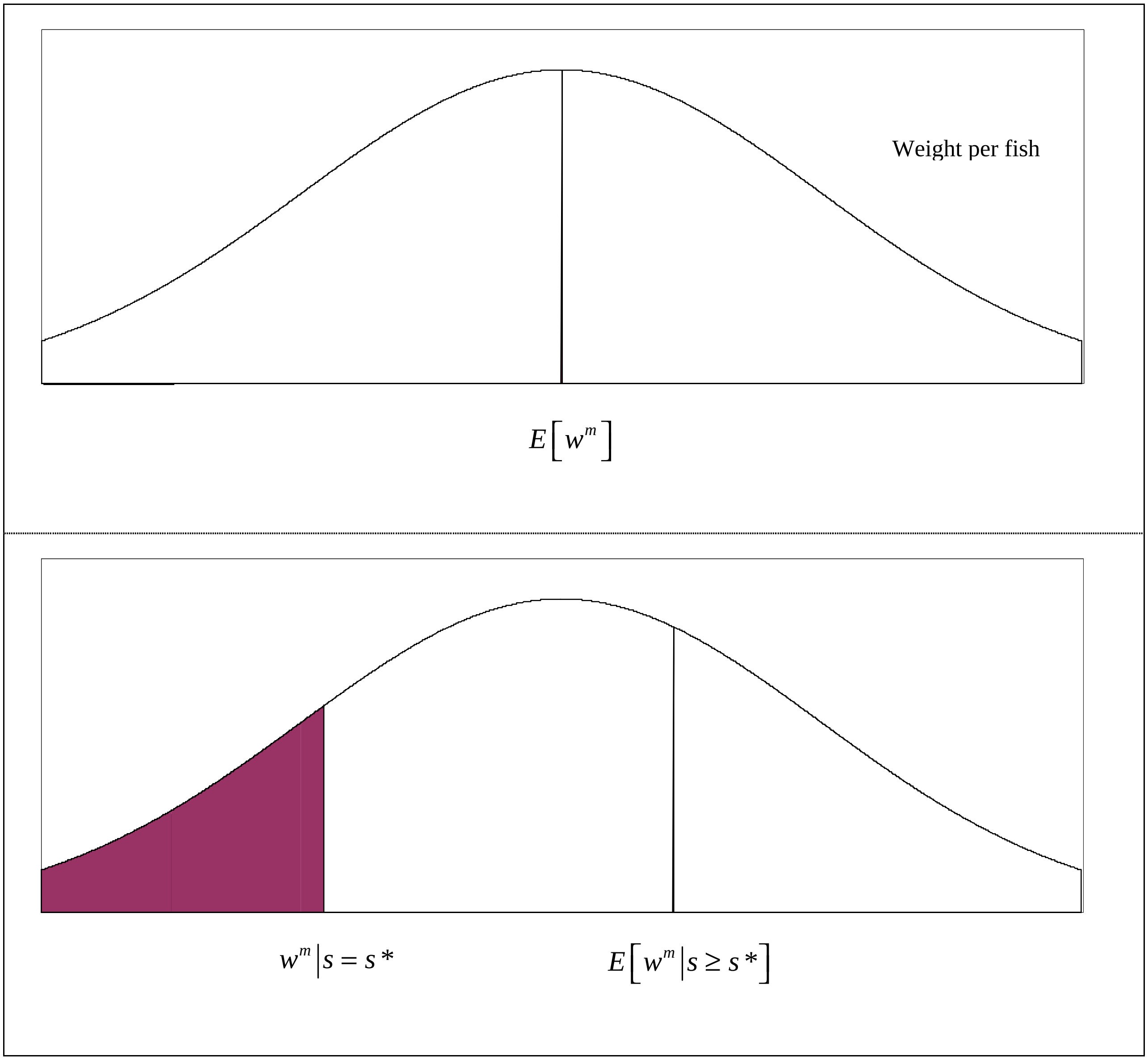

Figure 1. Expected Weight per Fish without and with a Mimimum Size Limit

The expression for the annual allocation of fish to mode *m* in (1) is adjusted for a minimum size limit as follows:

(5) $$h_t^m\left(s^*\right) = \bar{v}^m \frac{H_t}{\bar{w}^m\left(s^*\right)}$$

Although this adjustment is ad-hoc, it captures the basic effects of minimum size limits. As noted above, larger minimum sizes translate into larger expected weights per fish. A larger weight per fish decreases the number of fish available from the same level of biomass. Therefore, all else equal, larger minimum sizes reduce aggregate catch and keep in terms of the number of fish. The effort response equation translates these catch and keep reductions into reductions in the number of trips. In the end, larger minimum sizes lead to reductions in aggregate recreational fishing effort. Note, however, that this simple model ignores many important nuances of minimum size policies, such as high-grading and discard mortality (Woodward and Griffin, 2003).

2.2. Bag Limit Adjustment

For some management alternatives, the average catch per trip is constrained by a bag limit, *b*. In such cases, the predicted catch rate is governed by a check function:[5]

$$c_t^m(b) = \begin{cases} c_t^m \ \mathit{if} \ c_t^m \leq b \\ b \ \mathit{otherwise} \end{cases} \quad (6)$$

This check function is implemented after the effort response model has calculated the aggregate annual effort and catch rate. Therefore, effort does not explicitly respond to any changes in the average catch due to a binding bag limit. The minimum size and bag limit adjusted total harvest in pounds for mode m is given by

$$H_t^m(s^*, b) = c_t^m(b) \cdot E_t^m \cdot \bar{w}^m(s^*) \quad (7)$$

With this formulation, the adjusted annual harvest can be less than the harvest associated with the rebuilding plan to the extent that $H_t^m(s^*, b)$ differs from H_t^m. This can occur because the rebuilding plan estimates treat effort exogenously (Porch and Cass-Calay 2001). The simple trip adjustment model specified in (3) allows recreational effort to change in response to relative

[5] The censoring of the average catch rate in this manner implies assumptions about angler behavior and the relationship between the catch rate and stock abundance (Porch and Fox, 1990).

changes in the catch rate. These changes provide a richer depiction of fishery behavior, even though the changes do not feed back into the biological system as would be required for a full bioeconomic model. The general idea behind the bag limit analysis is illustrated in Figure 2 where the status quo harvest path is shown along with a strategy (STRAT1) path with and without a two fish bag limit. In the early years, the bag limit is not binding so the *with* and *without* paths coincide. However, after 2007 the harvest with the bag limit is everywhere less than the predicted harvest path with the rebuilding plan. The additional reduction in harvest due to endogenous effort in the model is shown as the cross-hatched area. In a more complete bioeconomic model, the surviving portion of this harvest reduction would feed back into the biological system.

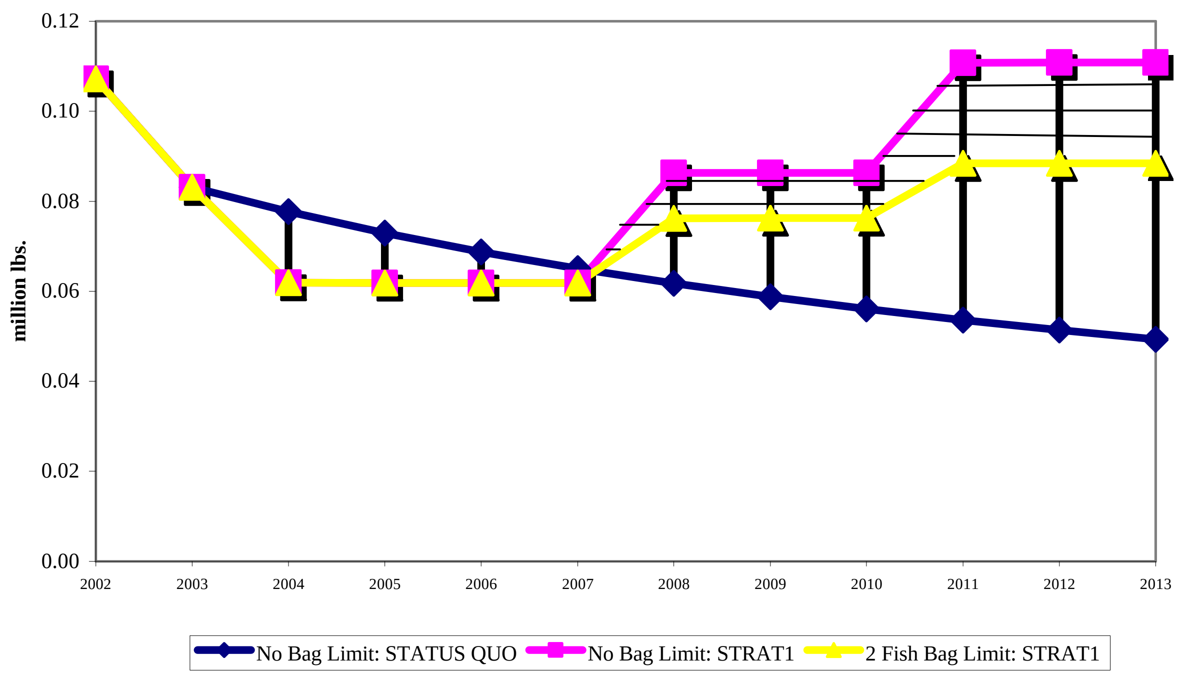

Figure 2. Hypothetical Aggregate Harvest with and without a Bag Limit

2.3. Seasonal Closure Adjustment

Seasonal closures prevent anglers from keeping fish during specific times of the year. Thus, a simple way to adjust predicted harvest for a seasonal closure is to reduce annual off-take by the percent of keep that historically occurred during the closed period. For example, if a policy proposes to close the fishery in June and July, and 35% of the keep typically occurs during these months, then the closure could result in a 35% reduction in harvest. This approach ignores, among other things, the possibility that anglers would shift effort to other times of the year. Note, also, that seasonal closures do not preclude anglers taking fishing trips or from keeping other species during the closed period. Any catches of the restricted species, however, must be discarded during the closed season. All discards are subject to release mortality so historic seasonal keep harvest rates may overstate potential reductions in recreational fishing mortality available from closures.

There are other issues with seasonal closures that stretch the abilities of the current model formulation to generate meaningful results. For example, results for seasonal closures using the constant percent reduction method will typically be indistinguishable from quota policies that offer the same reduction.[6] This may not be correct, however, because seasonal closures prescribe reductions during specific months, whereas quota reductions occur as soon as the limit is met (if at all). This could be before or after the seasonal closure months, but we cannot predict the outcome with the current model and data.

<u>Given the uncertainties and complications associated with the response to seasonal adjustments, there are no additional model adjustments for this policy</u>. Consequently, the results

[6] The welfare effects of the seasonal closures and quotas may also be indistinguishable if, as occurs for vermilion snapper, there is no information on the relative value of a kept fish at various points in the year.

for seasonal closures alone will be the same as the quota management strategy with the same rebuilding plan and recreational allocation.

2.4. Welfare Calculations

The simulated effort and catch rate vectors are used to calculate the related consumer surplus to anglers and the net revenues to for-hire operators.[7] The former is a simple linear transformation of the aggregate catch and keep and the latter is a function of the number of trips. Specifically, the predicted paths of adjusted effort and harvest are used to calculate the present value of each alternative to mode *m* as follows:

(8) $$PV^{m} = \sum_{t=t_0}^{T}\left\{\hat{h}_t^m CS^m\left[(1+r)^{t-t_0}\right]\right\} + \sum_{t=t_0}^{T}\left\{E_t^m NR^m\left[(1+r)^{t-t_0}\right]\right\}$$

where the time horizon runs from t_0 to T, CS^m is a mode specific estimate of consumer surplus per catch and keep, NR^m is mode specific operator net revenues per trip, and the term in brackets is a discount factor with discount rate r. Note that $NR^{private} = 0$ for the private boat mode. The discount rate applies a higher weight to near-term values. Thus, consumer surplus and net revenues achieved in early years of the rebuilding plan are given more weight than those achieved in later years. This is view is consistent with the notion of fisheries as *natural capital* (Clark and Munro 1994). The net present value to recreational anglers of each alterative *i* on mode *m* is calculated with reference to the present value of the status quo

(9) $$NPV^{m,i} = PV^{m,i} - PV^{m,status\ quo}$$

[7] *Consumer surplus per fish* is the value or well-being an angler receives from catching and keeping a fish over and above the amount they actually pay for that experience. *Net revenue per angler-trip* is the amount of money a for-hire operator collects from an angler over and above the amount it costs them to provide the trip.

This expression can also be modified to compare the relative present value of the different rebuilding plan management alternatives.

3. Data

3.1. Harvest Data

The Southeast Regional Office of the NOAA Fisheries provided the schedule of annual biomass and the yield associated with each rebuilding strategy, including the status quo. The allocation of the yield to the recreational sector varies by alternative as defined in Table 1. This allocation in pounds is converted to number of fish using an average weight per fish with the relevant minimum size limits following the procedure outlined in Section 2.1. The expected weight per fish is based on an average annual distribution of vermilion snapper length estimates. Table 3 and Table 4 show the annual distribution of fork length, FL, estimates for the private and charter boat modes, respectively, from the Marine Recreational Fishery Statistics Survey (MRFSS) in the Gulf of Mexico. The Tables also show the related total lengths in inches, *s*, and weight in pounds, *w*, based on the equations reported in Hood and Johnson (1999):

$$s = 1.13*FL - 0.102$$

$$w = 10^{2.87*Log10(s) - 3.225}$$

The distributions in Table 3 and Table 4 are used to calculate the average annual expected weight for the private and charter boat modes reported in Table 5. <u>For the present analysis, it is assumed that the expected weight of catch and keep from head boat passengers is the same as the weight estimated for charter boat anglers</u>. The average annual vermilion snapper harvest estimates and shares for each mode are shown in Table 6 based on the MRFSS, the Texas Parks & Wildlife Sportfishing Coastal Creel Survey (TPW), and the Head Boat Survey (HBS).

Table 3. Distribution of Vermilion Snapper Sizes in the Gulf of Mexico: Private Boats

FL	*s*	*w*	1998	1999	2000	2001	2002
7	7.8	0.2	0	0	0	0	0
8	8.9	0.3	0	0	1,751	66,871	4,977
9	10.1	0.5	1,485	2,681	9,065	47,721	14,611
10	11.2	0.6	1,954	10,561	3,467	20,807	47,455
11	12.3	0.8	3,403	26,492	4,109	51,272	54,716
12	13.5	1.0	4,572	16,347	9,459	21,091	31,934
13	14.6	1.3	3,197	12,427	296	9,563	13,398
14	15.7	1.6	0	6,719	0	12,404	6,351
15	16.8	2.0	0	1,560	0	3,361	4,942
16	18.0	2.4	0	612	0	900	0
17	19.1	2.8	0	1,011	0	900	0
18	20.2	3.3	0	0	0	900	0
19	21.4	3.9	0	0	0	900	0
20	22.5	4.5	0	0	0	0	0
22	24.8	6.0	0	0	0	0	0
23	25.9	6.8	0	0	0	0	0
24	27.0	7.7	0	0	0	0	0

Source: MRFSS Estimates (A + B1)

Table 4. Distribution of Vermilion Snapper Sizes in the Gulf of Mexico: Charter Boats

FL	*s*	*w*	1998	1999	2000	2001	2002
7	7.8	0.2	0	0	169	0	205
8	8.9	0.3	3,646	17,642	9,238	5,914	3,779
9	10.1	0.5	15,106	69,424	34,455	32,004	23,346
10	11.2	0.6	35,719	73,286	33,089	37,569	25,892
11	12.3	0.8	48,983	61,391	25,477	28,177	26,360
12	13.5	1.0	38,725	40,381	13,805	19,580	18,254
13	14.6	1.3	24,996	21,751	8,249	17,559	10,137
14	15.7	1.6	11,809	11,895	3,591	8,779	3,665
15	16.8	2.0	8,474	7,600	1,314	6,775	1,313
16	18.0	2.4	3,529	2,997	468	5,897	514
17	19.1	2.8	1,784	2,039	260	2,584	0
18	20.2	3.3	698	185	0	712	616
19	21.4	3.9	465	0	0	50	0
20	22.5	4.5	0	154	0	66	68
22	24.8	6.0	0	93	0	0	0
23	25.9	6.8	0	93	0	0	0
24	27.0	7.7	0	62	0	0	0

Source: MRFSS Estimates (A + B1)

Table 5. Average Pounds Per Vermilion Snapper with Different Minimum Sizes: 1998-2002

Minimum Size, s* (inches TL)	Private Boats, $\overline{w}(s*)^{private}$	Charter Boats, $\overline{w}(s*)^{charter}$	Head Boats, $\overline{w}(s*)^{head}$
10	0.886	0.885	0.885
11	0.973	0.991	0.991
12	1.056	1.152	1.152
13	1.242	1.372	1.372
14	1.483	1.633	1.633

Source: Author's calculations based on MRFSS Estimates

Table 6. Average Recreational Harvest of Vermilion snapper in the Gulf of Mexico by Mode

Mode, *m*	Years	Million Lbs.	% Share, $\overline{v}^m$
Private Boat	1998-2002	0.107	20
Charter Boat	1998-2002	0.247	46
Head Boat	1998-2002	0.182	34
Total	1998-2002	0.54	100

Sources: MRFSS, TPW, HBS

3.2. Effort Data

The MRFSS, TPW, and HBS do not report official estimates of the annual number of recreational fishing trips or days that specifically caught and kept vermilion snapper (or any other species). Therefore, the base period, t_0, catch and keep angler trip or day estimates are calculated as follows:

(10) $$E_0^m = \overline{q}^m \overline{z}^m$$

where $\overline{q}^m$ is the average annual number of recreational fishing trips estimated for mode *m* in the Gulf of Mexico from 1998 to 2002 and $\overline{z}^m$ is the annual proportion of angler trips that caught and kept vermilion snapper. The average number of trips, $\overline{q}^m$, is calculated using estimates of trips from the MRFSS and the TPW and estimates of angler days from the HBS. The base period estimates for trips in each mode are listed in the third column of Table 7.

The estimates of $\overline{z}^{private}$ and $\overline{z}^{charter}$ are based on the annual proportion of MRFSS trips from each mode that caught vermilion snapper.[8] For the head boat mode, the estimate of $\overline{z}^{head}$ is calculated as

(11) $$\overline{z}^{head} = ES^{head} * z^{head,east} + WS^{head} * z^{head,west}$$

where ES^{head} (55.8%) and WS^{head} (44.2%) are weights based on mean share of annual head boat angler days from eastern (West Florida) and western (Texas, Mississippi, Louisiana, Alabama) Gulf of Mexico, respectively, between 1986 and 1999; and $z^{head,east}$ (69.7%) and $z^{head,west}$ (30.7%) are the corresponding average percent of time spent targeting 'snapper' in the zones during 1997-1998 (Holland et al., 1999; Sutton et al., 1999). <u>'Snapper' target time was used because estimates of target time for vermilion snapper were not available for both zones</u>. The estimates of E_0^m and $\overline{z}^m$ for each mode are listed in the fourth column of Table 7.

Table 7. Average Recreational Trips and Proportion Catching and Keeping Vermilion snapper

Mode, *m*	Year	All Trips (millions), $\overline{q}^m$	% catching and keeping Vermilion snapper, $\overline{z}^m$	Vermilion snapper catch trips (millions), E_0^m
Private Boat	1998-2002	11.817	0.41%	0.05
Charter Boat	1998-2002	0.997	10.94%	0.11
Head Boat*	1998-2002	0.28	52.47%	0.15

Sources: MRFSS; Sutton et al. (Sutton et al., 1999); Holland, Fedler and Milon (1999)
*Head boat estimates are in terms of angler days and the '% for Vermilion snapper' estimate is for 'snapper' in general.

[8] Stephen Holiman at the NMFS Southeast Regional Office provided estimates of the annual proportion of MRFSS vermilion snapper catch trips in the Gulf of Mexico between 1986 and 2002.

3.3. Economic Parameters

There is no estimate of catch and keep rate elasticity, ε, for vermilion snapper in the Gulf of Mexico. The model uses the value of 1.46 from the (negative binomial type 1) red snapper trip demand model estimated by Gillig, Ozuna, and Griffin (2000) using MRFSS data for the Gulf of Mexico. Model runs with other elasticity values did not materially change the results.

The value per vermilion snapper kept used in the model is based on the estimates reported in Haab, Whitehead, and McConnell (2001). Vermilion snapper was not valued independently; rather it was included among other species in two different groupings. The relevant estimates for the bottom fish and snapper-grouper complexes are listed in Table 8. These measures of consumer surplus refer to the amount an individual angler is willing to pay on average for the opportunity to catch and keep an additional fish in each group, beyond the amount that they actually pay for such an experience. The bottom-fish estimates are generally higher than the snapper-grouper values because they are averaged over more species and incorporate all fishing modes. These features also make the bottom-fish estimates more consistent across the Gulf States and more appropriate for use in the present analysis. Therefore, the average Gulf-wide estimate of $3.02 per catch and keep of bottom fish is used for all modes. This value in 1997 dollars is inflated to the 2002 dollar amount of $3.72 using the 1982-84 base U.S. CPI from the Bureau of Labor Statistics.

Table 8. WTP/fish/trip Estimates in the Gulf of Mexico ($1997)

State	Bottom Fish/All Modes	Snapper-Grouper/ Private Mode
Alabama	2.94	0.23
Mississippi	3.05	0.35
Louisiana	2.98	1.04
Florida (Gulf)	3.09	3.52
average	3.02	1.29

Source: Tables 5-8 and 6-4 of Haab, Whitehead and McConnell (2001)

Average net revenues per trip for charter and head boat operators are calculated with information in Sutton et al. (1999) and Holland, Fedler and Milon (1999). For-hire operations can offer half day, full day, and overnight trip products. The average total annual angler days out for eastern and western zones of the Gulf of Mexico is given by a weighted sum of the average number of each trip product offered:

$$A^m = w1^m * 0.5 * d1^m * a1^m + w2^m * d2^m * a2^m + w3^m * 2 * d3^m * a3^m \qquad (12)$$

where $w1$, $w2$, $w3$ are the proportion of operators offering half, full, and overnight trips, respectively, $d1$, $d2$, $d3$ are the average number of half, full, and overnight trips, respectively (for operators who offer these types of trips), and $a1$, $a2$, $a3$ are the average number of half, full, and overnight passengers per trip, respectively (for operators who offer these types of trips). The data for the eastern and western zones of the Gulf of Mexico are listed in Table 9. Note that the estimates of $d1$-$d3$ and $a1$-$a3$ reported in Sutton et al. (1999) for the eastern Gulf of Mexico include zeros. Therefore, the proportion of operators in this zone offering each type of trip is set to one.

The average total revenue for charter and head boats is calculated as

$$R^{charter} = w1^{charter} * d1^{charter} * b1 + w2^{charter} * d2^{charter} * b2 + w3^{charter} * d3^{charter} * b3 \qquad (13)$$

$$\begin{aligned} R^{head} = {} & w1^{head} * d1^{head} * h1 * a1^{head} + w2^{head} * d2^{head} * h2 * a2^{head} \\ & + w3^{head} * d3^{head} * h3 * a3^{head} \end{aligned} \qquad (14)$$

where $b1$, $b2$, $b3$ are the average charter base fees for half, full, and overnight trips, respectively (for operators who offer these types of trips), and $h1$, $h2$, $h3$ are the average head fees for half, full, and overnight trips, respectively (for operators who offer these types of trips). For charter boat operators, it is assumed that the number of passengers does not exceed the amount included in the base fee. The average base and head fees are reported as 1997 dollars in Table 9.

A simple expression for the average net revenue per angler day out in each mode is

$$NR^m = \frac{R^m - C^m}{A^m} \tag{15}$$

where C^m is the average total annual cost for mode m. The expense categories and average amounts included in the total annual cost for charter and head boat operators by zone in the Gulf of Mexico are listed in Table 10. Note that expression (15) is only applicable to the charter and party boat modes. The NR estimates for the Gulf of Mexico are calculated as the sum of the estimates for the Western and Eastern zones, weighted by the historic share of trips (days) from these zones

$$NR^m = ES^m * NR^{m,east} + WS^m * NR^{m,west} \tag{16}$$

where the value for $ES^{charter}$ and $WS^{charter}$ are 71.5% and 28.5% , respectively, and the ES^{head} and WS^{head} are given above with respect to expression (11). The final estimates of net revenue per angler day out are inflated to the 2002 dollar amounts using the 1982 base U.S. PPI for number two diesel fuel from the Bureau of Labor Statistics. The final \$2002 estimates of average net revenue per angler day out used in the model are \$20.57 and \$47.75, respectively, for the charter and head boat modes in the Gulf of Mexico. The net revenue estimates are relatively high, but they don't include important cost elements such as the amortization of fixed costs and returns to operators. Future research is necessary to develop more accurate estimates of operator net revenues and profits. This could include additional data collections and formal econometric production analyses for the for-hire modes.

Table 9. Average For-Hire Operating Characteristics in the Gulf of Mexico by Zone in 1997

	Half Day		Full Day		Overnight	
Mode	E. Gulf	W. Gulf	E. Gulf	W. Gulf	E. Gulf	W. Gulf
	--PROPORTION OF OPERATORS OFFERING EACH TRIP TYPE, *w*--					
Charter	1.00	0.63	1.00	0.98	1.00	0.48
Headboat	1.00	0.81	1.00	1.00	1.00	0.57
	--NUMBER OF TRIPS, *d*--					
Charter	69.9	35.6	60.7	85.1	3.6	8.2
Headboat	206.4	67.1	74.0	176.7	-	8.7
	--NUMBER PASSENGERS PER TRIP, *a*--					
Charter	5.1	6.8	5.1	6.8	5.1	6.8
Headboat	25.4	38.1	25.4	38.1	25.4	38.1
	--FEES ($1997) PER TRIP (CHARTER, *b*) OR PASSENGER (HEAD, *h*)--					
Charter	308	417	526	762	1,349	1,993
Headboat	36	41	51	64	130	200

Sources: Sutton et al. (1999); Holland, Fedler and Milon (1999)

Table 10. Average For Hire Variable Costs by Gulf of Mexico Zone ($1997)

	Western Gulf		Eastern Gulf	
Expense Category	Charter	Head	Charter	Head
Bookkeeping Services	893	14,233	1,389	1,420
Advertising and Promotion	2,987	8,321	2,041	7,242
Fuel and Oil	10,256	61,367	8,224	18,020
Bait Expenses	2,573	14,171	2,022	6,353
Docking Fees	3,034	4,051	4,604	11,533
Food/Drink for Customers/Crew	418	2,000	1,191	0
Ice Expenses	1,028	2,515	824	1,799
Insurance Expenses	3,799	11,491	2,970	8,570
Maintenance Expenses	8,584	26,919	5,720	13,385
Permits and Licenses	986	1,238	890	2,158
Wage and Salary Expense	19,725	64,065	25,810	52,000
total	54,284	210,372	55,685	122,479

Sources: Sutton et al. (1999); Holland, Fedler and Milon (1999)

4. Results and Discussion

The results for the 13 management alternatives are summarized and ranked in Table 11. All results are given as deviations from the status quo. Since all the values in the table are positive, all policies provide an improvement over the status quo recreational fishery conditions. Note, however, that only the relative magnitudes and rankings of the estimates should be used for policy comparisons. Furthermore, caution should be exercised in comparing these estimates for the recreational sector with those for the commercial sector. It is not recommended that the numbers be used for harvest allocation decisions.

The quota policies (4, 7B, 7D, 7E) with the 33% allocation are the highest ranked management alternatives, primarily due to the higher recreational sector allocation. However, the value does not increase proportionately with the percent allocation. The allocation increase from 21 to 33 percent nearly doubles the net benefits available from any given rebuilding plan quota.[9]

The quota alternatives are roughly ranked according to the relative reduction offered. According to the stock assessment model, larger initial reductions offer compensating increases in abundance, harvest, and value in later periods. The exception is the *Steps (2010)* alternative. Apparently, the 50.5% initial reduction for this alternative is not offset enough in later periods to make this the highest ranking alternative. This is due to the discounting of net benefits, and the relatively higher opportunity cost of near term reductions in harvest. A lower discount rate would make Alternatives 7D and 8D more competitive.

[9] The increase in total net benefits attributed to the allocation increase for the quota policies is calculated by comparing results for Alternatives 7B-7D with those for Alternatives 8B-8D.

Alternatives 4 and 5 generate the same net benefits because the model does not explicitly adjust results for seasonal closures. The reasons for not adjusting for seasonal closures are discussed in the Model section. In sum, there is no information on the potential redistribution of effort with a closed season or on the relative value of reductions in harvest at different points in the year. Therefore, the effect of the seasonal closure in this analysis is, conservatively, the same as a quota of the same initial percent reduction.

The bag limit and minimum size policies are the lowest ranking management alternatives, mainly due to the way the model operates.[10] As modeled, management alternatives 2, 3A, and 3B consider the effect of bag and/or size limits on top of a quota equal to the rebuilding plan (*steps)* allowable catch for each mode in the recreational sector. This is a consequence of the assumption that all of the annual biomass and fish allocated to the recreational sector is harvested by anglers in each mode. Bag limits and minimum size limits act to restrict the number of fish available from any rebuilding plan allocation: the smaller the bag limit and the larger the minimum size, the lower the number of fish available. Consequently, since angling benefits are based on a value per fish, bag and/or size limits always generate less present value net benefits than a quota policy with any given rebuilding plan. A more complete bioeconomic model would allow results for the bag limit and minimum size policies to be considered independently of rebuilding plan quota policies.

The combined bag limit and minimum size alternatives (3A and 3B) generate the same results because the bag limits never become binding over the planning horizon: the average catch

[10] Note, however, that the 2 fish bag limit policy (Alt. 2) still ranks higher than a quota (Alt. 7A) that simply allocates more of the *Status quo* harvest to the recreational sector. In this case, the bag limit provides increased landings as the stock rebuilds due to the harvest reduction offered by the bag limit.

per trip never exceeds either bag limit (7 or 10) in any year. Thus, only the minimum size policy in these 'combined' management alternatives is effective. As modeled, larger minimum sizes translate into less fish available and, therefore, a lower amount of fish per trip. A bag limit is less likely to bind in this case.

Table 11. Results for the Economic Analysis of the Recreational Sector: Deviations from the Status Quo 2004 - 2013

Alt.	- Million $ -			Rank
	Consumer Surplus	Net Revenues	Total	
2	1.67	7.40	9.08	8
3A	1.37	3.63	5.00	10
3B	1.37	3.63	5.00	10
4	9.93	25.31	35.24	3
5	2.68	7.40	10.09	7
7A	2.11	6.12	8.23	9
7B	6.87	18.62	25.49	4
7D	10.84	26.23	37.07	2
7E	12.86	30.69	43.55	1
8B	0.79	2.46	3.25	11
8C	2.68	7.40	10.09	7
8D	3.26	8.09	11.35	6
8E	4.54	11.47	16.01	5

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6. Appendix: *Mathematica* Workbook for the Analytical Solution to the Catch Rate Elasticity Model

Model Formulation

- **Define the catch rate as the average catch per trip at time t**

In[2]:=
```
c[t_] := C_t / Q_t
```

$$c[t\_] := \frac{C_t}{Q_t}$$

where C_t and Q_t are, respectively, the aggregate number of fish harvested and the aggregate number of trips.

Define the catch elasticity as the percent change in aggregate trips for a percent change in the catch rate

In[3]:=

$$\text{elast} = \frac{Q_t - Q_{t-1}}{0.5\,(Q_t + Q_{t-1})} \Big/ \frac{c[t] - c[t-1]}{0.5\,(c[t] + c[t-1])}$$

Out[3]=

$$\frac{1.\left(\frac{C_{-1+t}}{Q_{-1+t}} + \frac{C_t}{Q_t}\right)(-Q_{-1+t} + Q_t)}{\left(-\frac{C_{-1+t}}{Q_{-1+t}} + \frac{C_t}{Q_t}\right)(Q_{-1+t} + Q_t)}$$

Solve the elasticity equation to get an expression for Q_t as a function of all other variables

In[4]:=
```
trips = FullSimplify[Solve[elast == ε, Q_t]]
```

Out[4]=

$$\left\{\left\{Q_t \to \frac{1}{(1. + 1.\,\varepsilon)\,C_{-1+t}}\left((-1. + 1.\,\varepsilon)(-0.5\,C_{-1+t} + 0.5\,C_t)\,Q_{-1+t} - 0.5\sqrt{\left(\left(1.\,(-1. + \varepsilon)^2 C_{-1+t}^2 + 2.\,(0.171573 + \varepsilon)(5.82843 + \varepsilon)\,C_{-1+t}\,C_t + 1.\,(-1. + \varepsilon)^2 C_t^2\right) Q_{-1+t}^2\right)}\right)\right\},\right.$$
$$\left.\left\{Q_t \to \frac{1}{(1. + 1.\,\varepsilon)\,C_{-1+t}}\left((-1. + 1.\,\varepsilon)(-0.5\,C_{-1+t} + 0.5\,C_t)\,Q_{-1+t} + 0.5\sqrt{\left(\left(1.\,(-1. + \varepsilon)^2 C_{-1+t}^2 + 2.\,(0.171573 + \varepsilon)(5.82843 + \varepsilon)\,C_{-1+t}\,C_t + 1.\,(-1. + \varepsilon)^2 C_t^2\right) Q_{-1+t}^2\right)}\right)\right\}\right\}$$

where ε is a constant elasticity. Only the second solution is valid because the first solution yields negative values. Check this using plausible numbers for the model variables and parameters:

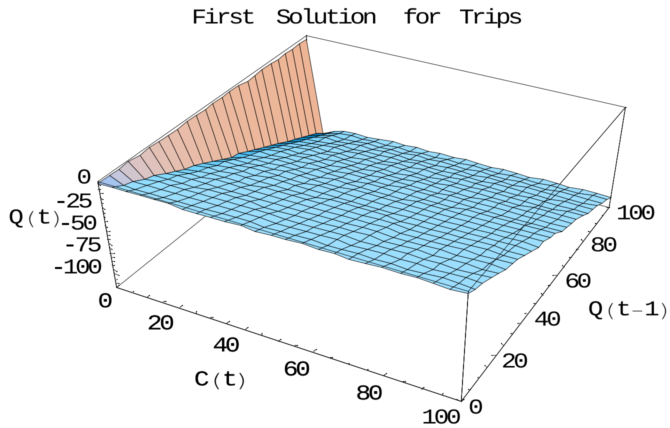
In[5]:=
```
trips /. {ε → 1.46, C_(t-1) → .17, C_t → .16, Q_(t-1) -> .046}
```

Out[5]=

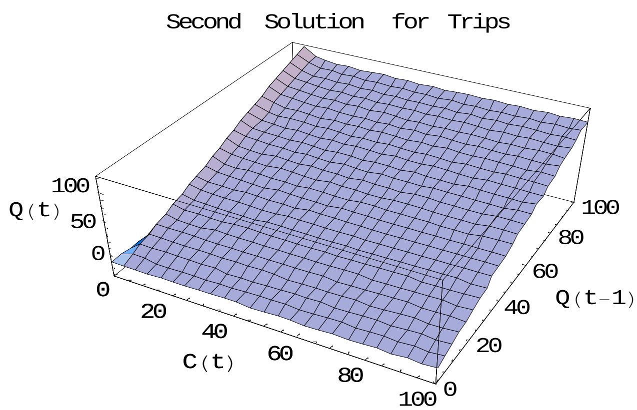
$$\{\{Q_t \to -0.0448803\},\ \{Q_t \to 0.0443743\}\}$$

Plotting over a range of values for catch and lagged trips reafirms that the first solution is everywhere negative, while the second solution is everywhere positive.

```
In[6]:=  Plot3D[Qt /. trips[[1]] /.
           {ε → 1.46, Ct-1 → (x - 1), Ct → x, Qt-1 → y},
          {x, 0, 100}, {y, 0, 100},
          PlotLabel→ "First Solution for Trips",
          AxesLabel→ {"C(t)", "Q(t-1)", "Q(t)"}];
```




```
In[7]:=  Plot3D[Qt /. trips[[2]] /.
           {ε → 1.46, Ct-1 → (x - 1), Ct → x, Qt-1 → y},
          {x, 0, 100}, {y, 0, 100},
          PlotLabel→ "Second Solution for Trips",
          AxesLabel→ {"C(t)", "Q(t-1)", "Q(t)"}];
```



Use the second trips solution to define a general expression for trip dynamics

```
In[8]:=  Qt[elast_, Ct1_, Ct_, Qt1_] :=
          Qt /. trips[[2]] /. {ε → elast, Ct-1 → Ct1, Ct → Ct, Qt-1 → Qt1}
```

Vermilion Snapper Example

This example is taken from the 2004 Rebuilding Plan for Vermilion Snapper in the Gulf of Mexico. It is based on Alternative 7B for the private boat mode in the recreational sector. See the rebuilding plan document for more information on the parameters and starting values used.

Load required packages, yield data, and define model parameters

In[9]:=
```
<< Statistics`DataManipulation`
<< Graphics`MultipleListPlot`
<< Graphics`FilledPlot`
```

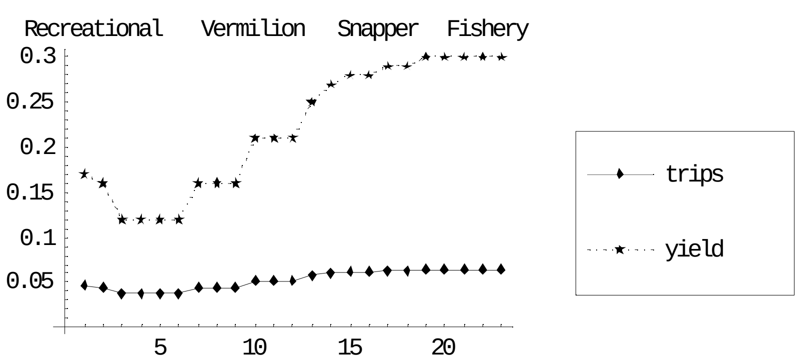
In[12]:=
```
SetDirectory["C:\Documents and Settings\DCARTER\
    Desktop\working\projects\vermilionSnapper\pgms"];
dataset = Import["vsYieldConstH.csv"];
yield = Flatten[dataset] ;
elasticity = 1.46;
startTrips = 0.0461277508514796;
```

Define a vector to hold the stream of private trips and populate it using the effort response model and the yield

In[17]:=
```
pTrips = Table[startTrips, {Length[yield]}];
Do[pTrips[[i + 1]] =
  Qt[elasticity, yield[[i]], yield[[i + 1]], pTrips[[i]]],
 {i, 1, Length[yield] - 1}]
```

Graph the yield and trips over time

In[19]:=
```
MultipleListPlot[pTrips, yield,
  PlotLabel -> "Recreational Vermilion Snapper Fishery",
  PlotJoined → True,
  PlotLegend → {"trips", "yield"}];
```



Calculate the catch rate and an ex-post catch elasticity using the yield streams and predicted trips

In[20]:=

```
cr = yield / pTrips;
exElast = Table[1, {Length[yield]}];
Do[exElast[[i]] =
  elast /. {Ct → yield[[i]], Ct-1 → yield[[i - 1]],
    Qt → pTrips[[i]], Qt-1 → pTrips[[i - 1]]},
 {i, 2, Length[pTrips]}]
```

Table of results

In[23]:=

```
TableForm[
 Transpose[{yield, pTrips, cr, exElast}], TableHeadings ->
  {Automatic, {"yield", "Trips", "CR", "ExElast"}}]
```

Out[23]//TableForm=

	yield	Trips	CR	ExElast
1	0.17	0.0461278	3.68542	1
2	0.16	0.0444975	3.59571	1.46
3	0.12	0.0375099	3.19915	1.46
4	0.12	0.0375099	3.19915	Indeterminate
5	0.12	0.0375099	3.19915	Indeterminate
6	0.12	0.0375099	3.19915	Indeterminate
7	0.16	0.0444975	3.59571	1.46
8	0.16	0.0444975	3.59571	Indeterminate
9	0.16	0.0444975	3.59571	Indeterminate
10	0.21	0.052295	4.01568	1.46
11	0.21	0.052295	4.01568	-0.599914
12	0.21	0.052295	4.01568	-0.599914
13	0.25	0.0579974	4.31054	1.46
14	0.27	0.0607081	4.44752	1.46
15	0.28	0.0620326	4.51375	1.46
16	0.28	0.0620326	4.51375	Indeterminate
17	0.29	0.0633381	4.5786	1.46
18	0.29	0.0633381	4.5786	Indeterminate
19	0.3	0.0646254	4.64214	1.46
20	0.3	0.0646254	4.64214	-1.12237
21	0.3	0.0646254	4.64214	Indeterminate
22	0.3	0.0646254	4.64214	Indeterminate
23	0.3	0.0646254	4.64214	Indeterminate

The indeterminant results occur where the catch rate does not change from year to year. In this case the denominator of the ex-post catch elasticity is 0. This is a problem with the exact analytical solution in *Mathematica*, but not in the numerical methods of Excel.